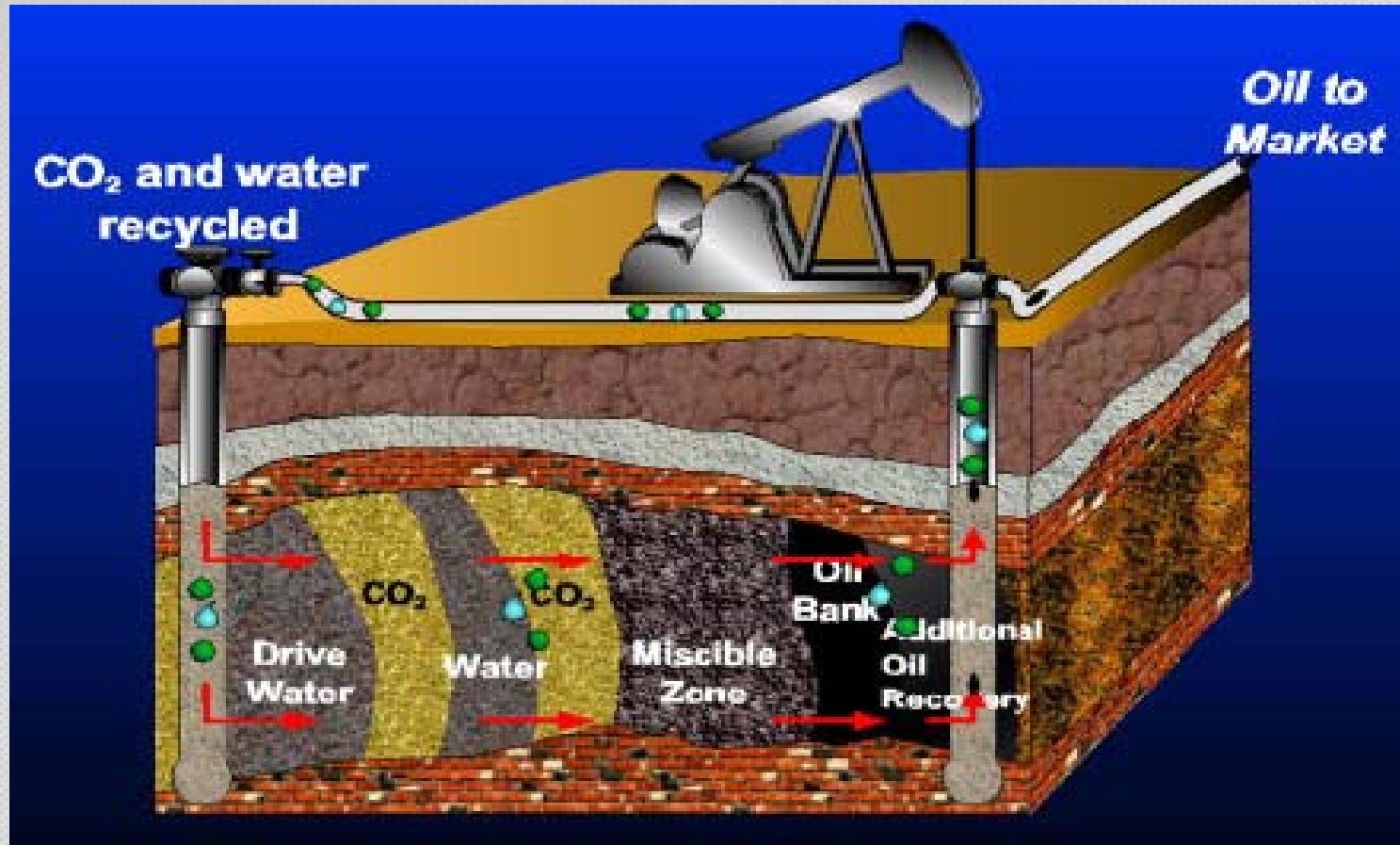


Enhanced Oil Recovery

Schematic C02 Displacement

Schematic C02 Displacement



Introduction

- Theoretically, CO₂ miscible/immiscible injection can be applied to all developed oil fields because of its vaporization capability better than other components, N₂ and C₁
- CO₂ is considered as one of the two green house gases, the other one is C₁. It is blamed for one of the global warming factors
- Currently, the environment issue is a major factor for any new project, especially, Kyoto agreement deal with CO₂ problem
- CO₂ Sources are:
 - Natural deposits
 - Industrial waste – by product of power plants or petroleum processing facilities
- To reduce the industrial waste, CO₂ injection into developed oil fields (CO₂ sequestration) is a good business (even it is immiscible) for oil companies due to government incentives in Canada

Advantages of CO₂ Miscible Injection

- CO₂ can improve oil recovery because it can reduce the fluid and rock interfacial tension (IFT), reduction in oil viscosity, and swelling of oil
- CO₂ can vaporize light and intermediates components from oil even it is immiscible better than methane or nitrogen
- Reducing green house gas emission to atmosphere

CO₂ Miscible Process

- The major mechanisms for CO₂ immiscible process are:
 - ❖ Swelling of oil
 - ❖ Reduction of viscosity
 - ❖ Pressure maintenance
- The first two mechanisms can be quantified in laboratory
- The third one is used for CO₂ sequestration to be cost effective

CO₂ sequestration

- To ensure CO₂ sequestration to be both cost effective and environmentally safe, it requires geologic modeling and numerical simulation to study the feasibility of injection into porous media
- Laboratory tests and reaction path simulation are used to investigate the fate of injected CO₂ with reservoir fluid and mineral during static tests with reservoir core and brines
- Modeling will be used to predict storage capacity and physical and chemical changes in reservoir properties such as fluid compositions, porosity, permeability, and phase relation

Reservoir pressure maintenance

- In general, one likes to use nitrogen (N_2) rather than CO_2
- N_2 is cheaper than CO_2
- However, if CO_2 is readily available and cheap (incentive from government), CO_2 can provide a better oil recovery than N_2
- This is due to CO_2 can dissolve in oil and swells oil much better than N_2

Lessons from two successful CO₂ immiscible projects

- Trinidad – medium oil (API from 17 to 29) using industrial waste
 - ❑ Transmissibility (kh/μ) > 500 provided superior performance
 - ❑ CO₂ supply interruptions did not seem to hurt overall incremental recovery
 - ❑ Pressure support is important
 - ❑ Injection strategy was optimized by simulation to mobilize residual oil
 - ❑ Monitor produced gas-oil ratio closely and continuously
 - ❑ High injection rates are wasteful, lead to CO₂ channeling. This will be discussed later
- Bati Raman, Turkey – heavy oil (API=12, $\mu=592$ cp) using natural source
 - ❑ with plenty of CO₂ injection (natural sources) and good planning (using simulation) based on piloting experience
 - ❑ Reservoir is highly fractured

Both projects use simulation to guide their field development stage by stage.

Bati CO₂ Immiscible in a fractured reservoir

- Calculation or approaches not supported by a pilot could give misleading results when evaluating the success of the method
- A laboratory scale pilot can be carried out first using preserved cores. The pilot can be conducted Huff 'n' Puff in the field
- During this field piloting, it is important to observe the injection and production pressure variation.
- If the injecting pressure can not be built up, that is due to leaky reservoir
- On other hand, the injecting pressure builds up too quick and when put back to production the pressure declines fast. This could be due to no fracture to transfer injected CO₂

Conclusions and Recommendations

- CO₂ miscible process can be applied to almost all depleted reservoirs for different purposes
- CO₂ miscible flooding has been applied successfully to medium and heavy oil
- To evaluate this process, economic consideration is the most important factor
- Safety is another factor to be considered for CO₂ sequestration purpose
- Before conducting a field project, it requires some laboratory tests, field piloting, and simulation
- Evaluation the adaptability of the technology of carbon dioxide miscible injecting to developed fields should be based on, mainly, economic
- Simulation plays an important role in evaluating CO₂ miscible/immiscible injection

Development and case study of the Technology of CO₂ Projects in Canada

Introduction

- Most CO₂ field projects in Canada are initially designed to be miscible.
- There are no CO₂ immiscible field projects in Canada.
- Currently, 32 CO₂ projects are planning due to government incentive in Canada.
- Six field projects and one CO₂ – coal bed methane recovery pilot are undergoing.
- The largest CO₂ field projects is Weyburn that being considered a successfully CO₂ sequestration
- I had designed 10 different CO₂ miscible projects, 8 in Canada and 2 in Libya, laboratory and conducted simulation stages.
- Recently, there are two new projects being approved by Alberta government, Apache and Devon, using gas plants exhausted CO₂.

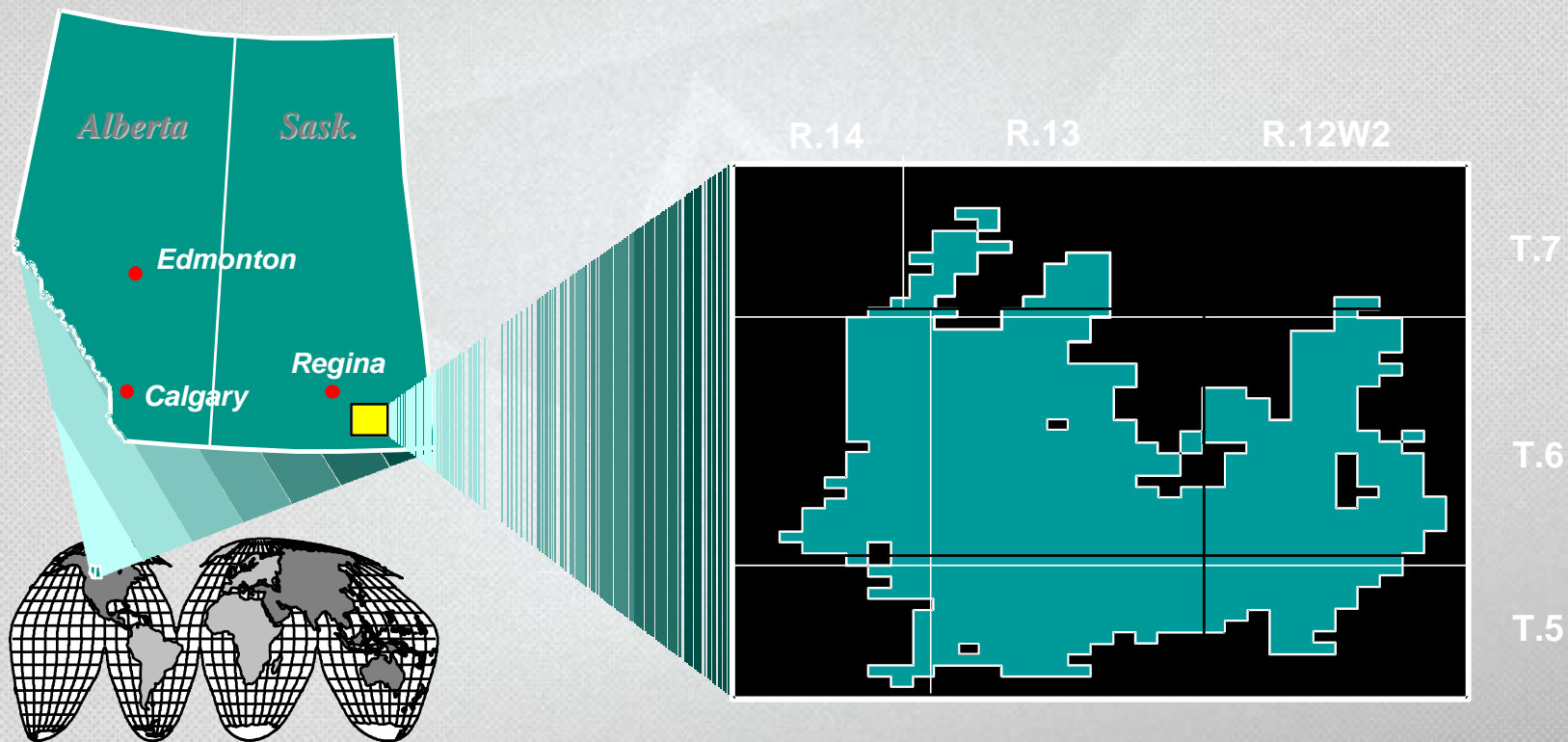
Why Canada pursue CO₂ storage?

- CO₂ storage under land is one of a bundle of measures that could help buy time while convert from fossil fuels
- Need carefully monitored pilot projects to learn more about risks before deciding
- Public should have opportunity to determine if acceptable
- If risks are found acceptable, CO₂ storage could be included in emissions trading schemes

Geological Storage Requirement

- Source of concentrated CO₂
 - CO₂ from natural gas, ~10 Mt/yr in 2010 (Canada)
 - CO₂ from hydrogen production for bitumen upgrading (oil sands), ~ 10Mt/yr in 2010 (Canada)
 - future: coal-fired electricity – IGCC process (“clean coal”)
- Suitable geologic formations
 - enhanced oil recovery in active wells
 - storage in depleted oil and gas reservoirs
 - enhanced coalbed methane recovery in deep coal seams
 - injection into deep saline aquifers
 - storage in salt caverns
- Source and sink in the same geographic location
 - e.g. Alberta – CO₂ storage capacity in W. Canada: 15 Gt

Weyburn Project Location



Weyburn field

- Investment in the Weyburn project is \$1.3 billion representing a finding cost of approximately \$10/bbl.
- Water injection volume was 156,526 bopd in April 2003 with CO₂ injection volume of 70-90 million standard cubic feet per day (MMcfpd).
- The two principal carbonate reservoirs being CO₂ flooded in Weyburn field are the Vuggy Limestone and Marly Dolomite of the Midale formation.
- The average net pay zone thickness is between 10 and 89 feet.
- The Marley Dolomite zone has a porosity of 26% with a permeability of 10 millidarcies (md). The Vuggy Limestone has a porosity of 15% with a permeability of 30 md.
- The bottom hole temperature is 151 degrees Fahrenheit.
- The Midale oil viscosity is 0.5 centipoise (cp) at reservoir conditions with an initial formation volume factor (Boi) of 1.46 rb/stb.
- The CO₂ minimum miscibility pressure (MMP) for the Midale oil is between 1,912 psi and 2,408 psi

Weyburn project

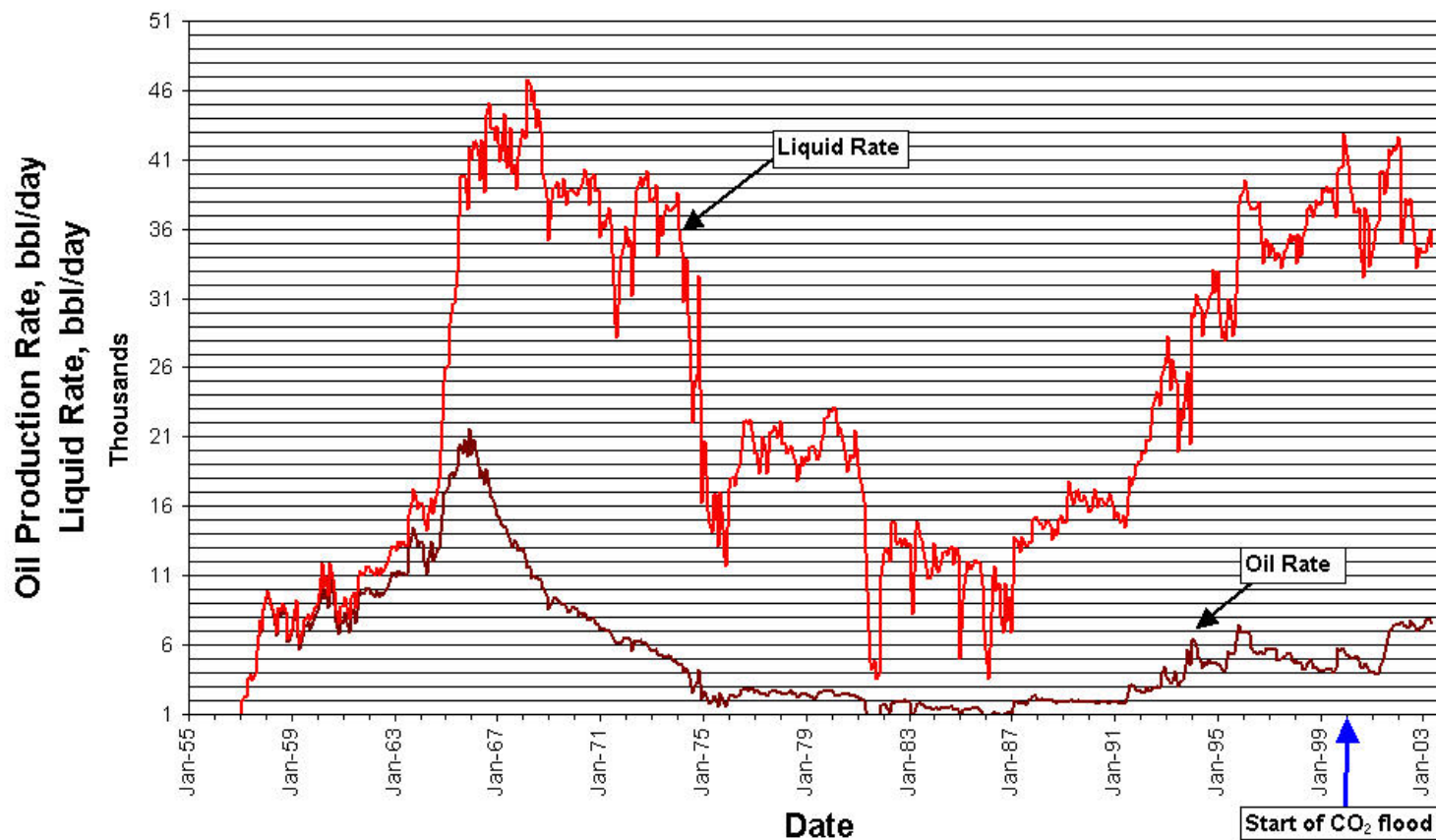
- The laboratory portion was designed by Saskatchewan Research Council (SRC) using rising bubble and slim tube tests to confirm the miscible pressure
- Simulation was conducted by EnCana, operator
- CO₂ source is transported by pipelines from US, next slide
- Drying is necessary for CO₂ transportation to prevent CO₂ – hydrate
- CO₂ conditioning (removed surface) may be critical to the success retrofit strategies for CO₂ recover from boilers
- Transported cost may be US\$0.6 to \$1.25 / Mscf
- The CO₂ pipelines considered are located all in parts of country that have low population areas
- Supercritical operation conditions offers technical advantages because higher gas densities can be achieved when two-phase flow concerns are eliminated
- Pipeline safety is always concerns
- Field monitoring
 - Cross well seismic
 - Geochemical sampling
 - Repeat surface seismic
 - Tracers confirming flow path

CO₂ source for Weyburn Project

250 million cu.ft. per day
 CO₂ by-product of coal
 gasification
 95 million cu.ft. per day
 contracted for Weyburn
 project
 320 km pipeline
 CO₂ purity 95%
 CO₂ pressure 14MPa

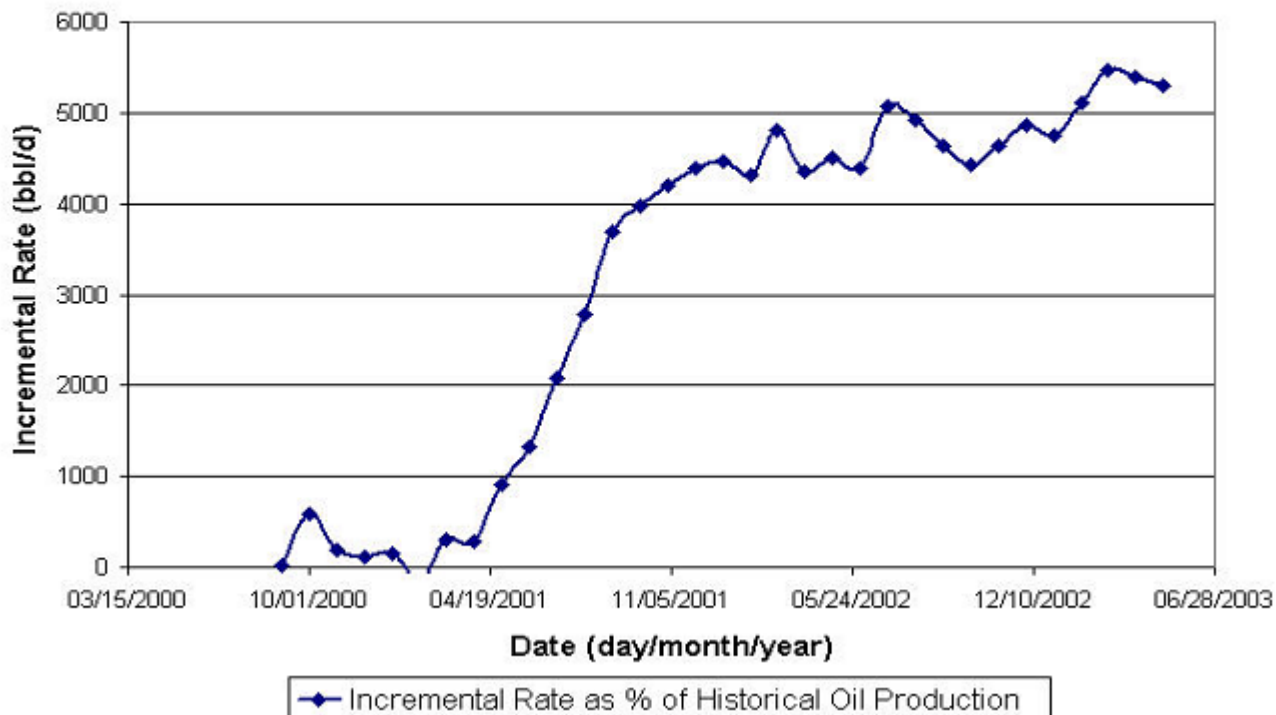


Weyburn Public Data until May 2003
 EOR area
 242 Wells

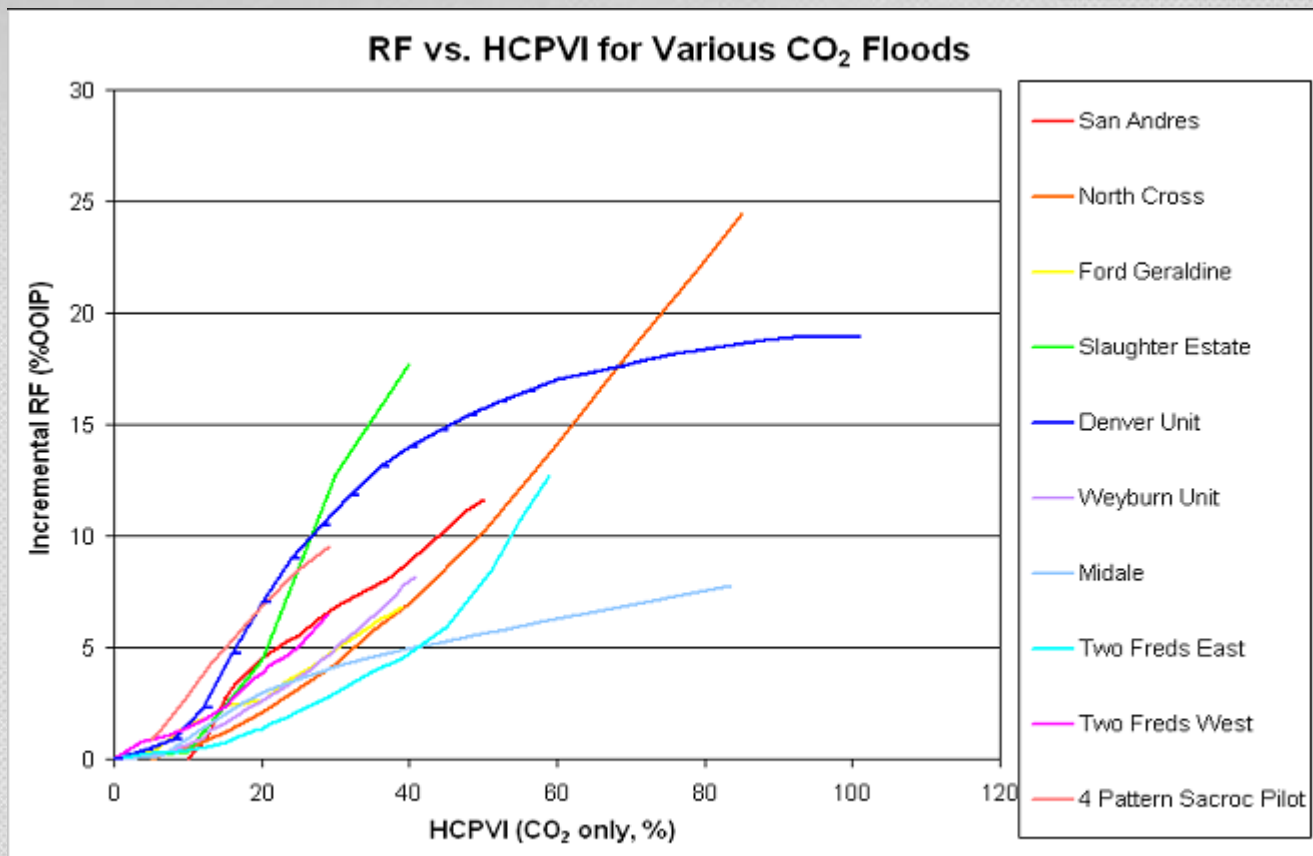


TSX-V:PTR

**Incremental Rate as % of Historical Oil Production
Weyburn Field - EOR response**



TSX-V:PTR



SPE paper 35391, SPE monograph Stalkup, SPE paper 26391.

Organizations involved in Weyburn Project

- **Canada**

- Saskatchewan Energy & Mines
- Saskatchewan Research Council
- University of Alberta
- University of Calgary
- University of Saskatchewan
- University of Regina
- Alberta Research Council
- PanCanadian Resources
- JD Mollard & Associates

- **European Community**

- British Geological Survey, Britain
- Bureau de Recherches Geologiques et Minieres, France
- Institut Francais du Petrole (IFP), France
- Danish Geological Survey, Denmark
- Italian National Institute of Geoscience

- **USA**

- Lawrence Berkeley National Laboratory, Berkeley, CA
- Colorado School of Mines
- Monitor Scientific (Colorado)

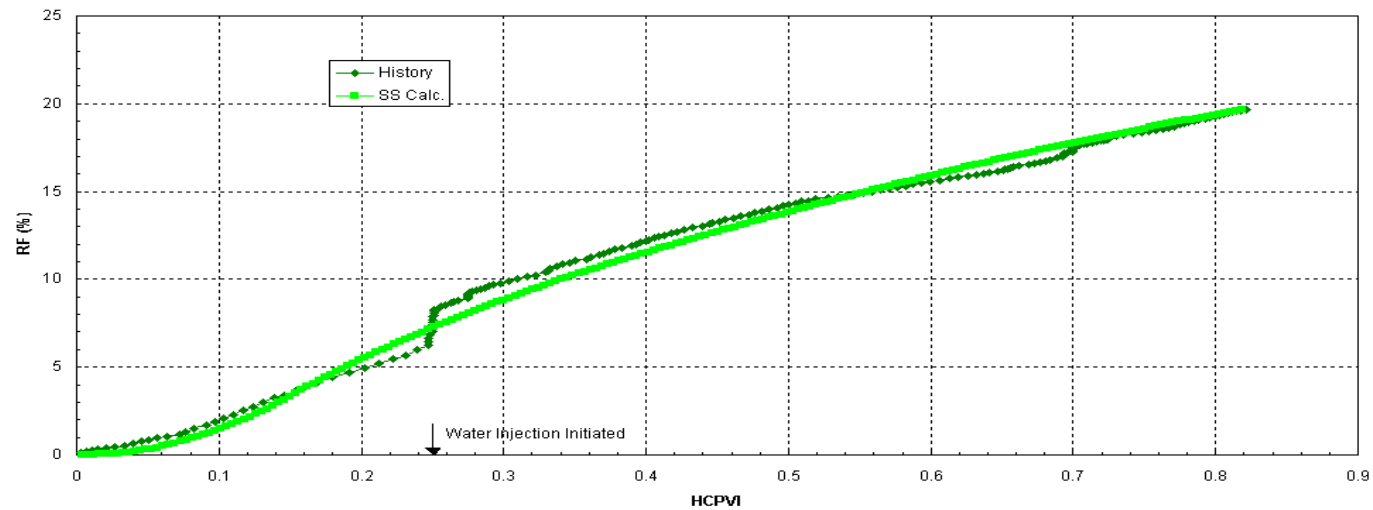
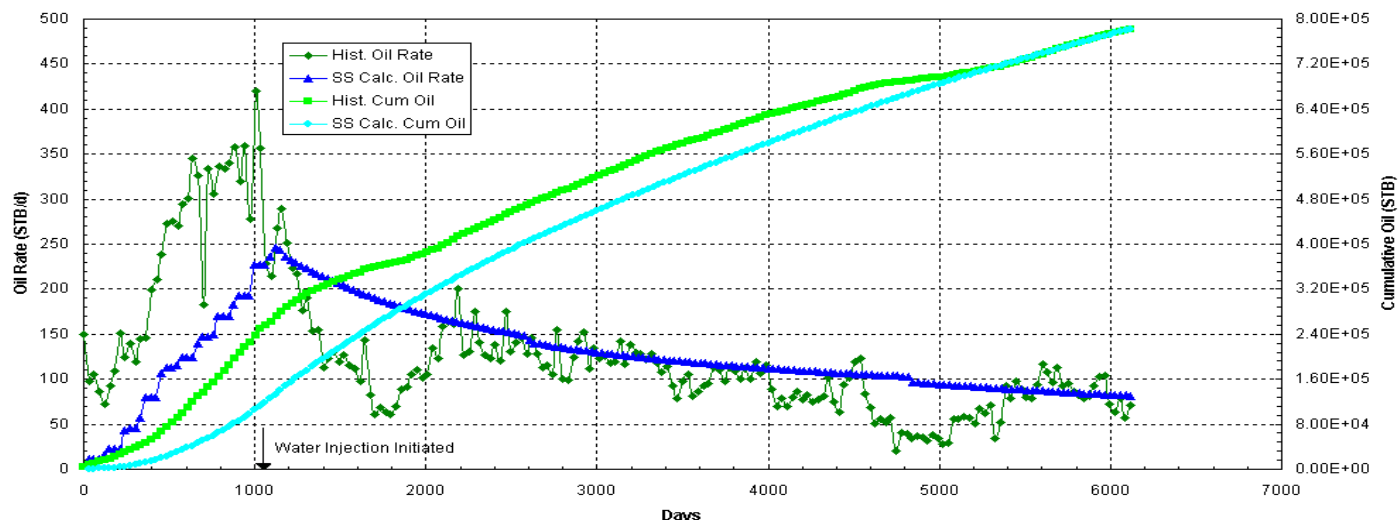
Project Organizational Chart



Joffre project

- Initially, Joffre was operated by ESSO, CO₂ miscible study, laboratory and simulation were conducted for this field
- CO₂ was trucked from a power plant
- This project lasted 3 years and was shut-down due to economic reason
- Equation of state was used to determine the CO₂ MMP and it took three slim tube experiments to confirm the EOS prediction
- Based on the study, there is no asphaltene precipitation for this oil

Joffre Project results



CO₂ –Coal Bed Methane

- Burlington Resources
- Single well Piloting Huff 'n' Puff
- No results are available in public

CONCLUSIONS



- Canada government is vigorously pursuing CO₂ storage in oil field to meet Kyoto agreement.
- Weyburn CO₂ project is an integrated management approach and is considered the most successful international CO₂ sequestration project.
- Cooperative approach will aid implementation.



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